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Low Frequency Volume Scatter and Accompanying Bioacoustic Measurements in the Gulf of Alaska

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PREFACE

This work was performed under NUWC Project Number A60800, Critical Sea Test (CST) Program. The Principal Investigator is M.J. Vaccaro, Code 3112 (formerly J.M. Monti, Code 33A) and the Program Manager is R.G. Malone, Code 33A (formerly J.M. Syck, Code 3112). The sponsoring activity is the Space and Naval Warfare Command (SPAWAR, PMW 182-52, C.I. Bohman).

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13. ABSTRACT (Maximum 200 words)

Volume scattering from 200 to 1500 Hz was measured during the Gulf of Alaska surface scatter and air/sea interaction experiment occurring in February 1992. Scattering strength as a function of frequency and depth was measured and layer strength and column strength were calculated using a vertically bistatic measurement technique developed by Stockhausen and Figoli [SACLANT ASW Research Center Technical Report No. 225, 15 May 1973]. These measurements were accompanied by concurrent measurements of size/depth distributions of the fish population present using a dual beam echosounder system. Fish distributions were used to predict layer and column strength by employing the NUWC Interval Column Strength Model developed by Saenger et al. [Naval Underwater Systems Center Technical Report No. 9001, 31 December 1991]. Comparisons of the measured and predicted results show that low frequency scattering resonances may be related to biologics.

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Measurement Objectives

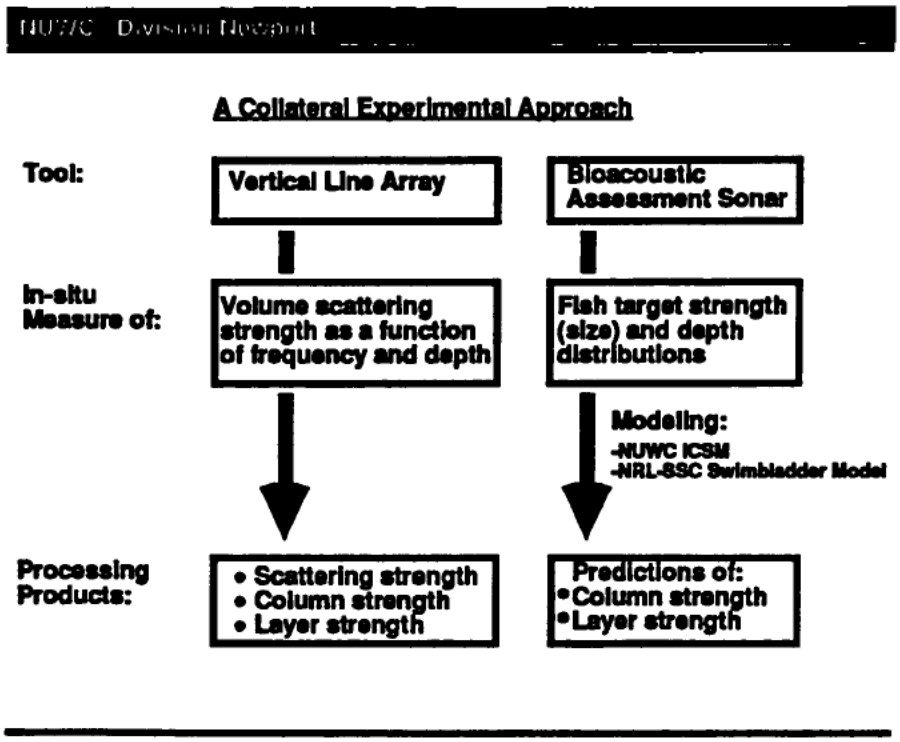
- **To make direct path measurements of volume scattering using a vertical line array (VLA) coincident to surface scatter and distant reverberation measurements.**

- **To make collateral measurements of the size/depth distribution of biological scatterers in the area for input into predictive models of layer and column strength.**

- **To demonstrate the feasibility of using a high frequency bioacoustic assessment sonar to predict low frequency volume scattering.**

VuGraph 1

There is a genuine interest in the sonar community to utilize high frequency bioacoustic survey data for the purpose of predicting low frequency volume (biological) scattering characteristics. The Gulf of Alaska surface scatter and air/sea interaction experiment which occurred in February 1992, was a unique opportunity to demonstrate the feasibility of such a measurement approach. During this experiment, low frequency (200-1500 Hz) volume (biological) scattering measurements, using SUS explosives in conjunction with a Vertical Line Array (VLA), were concurrently conducted with measurements of the size/depth distributions of the fish population in the vicinity of the acoustic stations, using a high frequency dual beam echosounder system. The experimental objectives of this low frequency, direct path volume scatter and the accompanying high frequency bioacoustic measurements are listed in VuGraph #1.



VuGraph 2

The collateral experimental approach used for these Gulf of Alaska measurements is delineated in VuGraph #2. The measurement systems used were (1) a VLA receiver in conjunction with SUS explosive sources, and (2) a Dual beam bioacoustic assessment sonar system built and operated by personnel from BioSonics Inc., Seattle, WA.

Processing of the bioassessment sonar data provides input parameters for the column strength prediction models developed by NUWC and NRL-SSC (formerly NOARL).

The column strength spectra derived from both the SUS/VLA measurement system and the bioacoustic modeling yielded a basis of comparison to assess the feasibility of making high frequency (≈120 kHz) bioacoustic measurements to estimate low frequency (200-1500 Hz) volume scattering effects.

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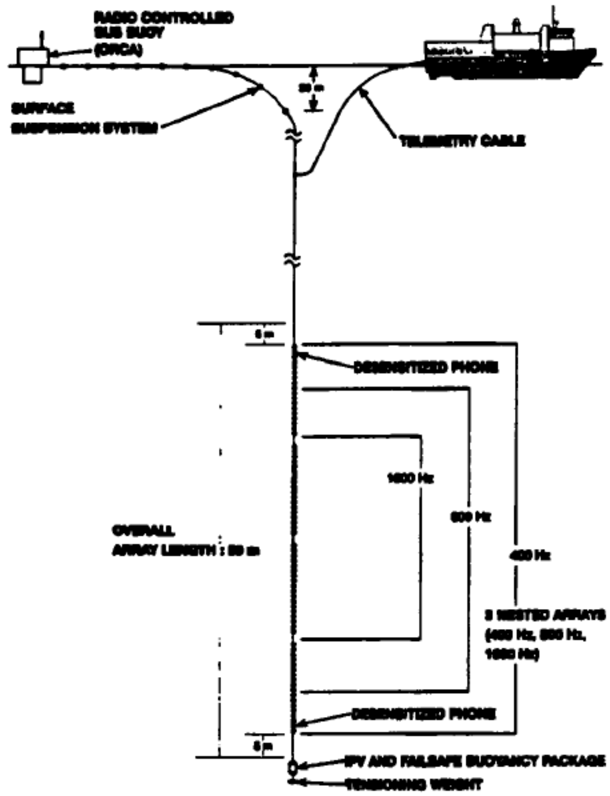
VERTICAL LINE ARRAY (VLA) SCHEMATIC DIAGRAM



VuGraph 3

Depicted in VuGraph #3 is the technique used to make direct path measurements of volume scatter in the upper 600 m of the water column. A VLA is deployed to a depth of ≈750 m. The VLA consists of three nested apertures containing 32-hydrophones each where half-wavelength spacing is used at the design frequencies of 400, 800 and 1600 Hz; i.e., the LF, MF and HF subarrays. The acoustic source used in these measurements is a SUS Mk 59, 4-lb explosive charge which is deployed from the surface using a remotely controlled SUS deployment system known as the Ocean Reverberation Charge Actuator (ORCA) buoy. The SUS are set to detonate at a depth of ≈910 m (i.e., ≈160 m below the array) resulting in a vertically bistatic measurement geometry. This technique was originally developed by Stockhausen and Figoli (1973) to measure the scattering strength of deep biologic layers.

Upward looking endfire beams are formed with the VLA LF, MF and HF apertures and the backscattered energy received in each beam is processed to yield volume scatter and column strength for the upper 600 m. By processing only up to 95% of the each aperture design frequency, the downward ambiguity sidelobe is eliminated, yielding sidelobe levels which are approximately 40 dB down. Full beamwidth varies from 32 to 47 degrees.

It should be noted that the ORCA buoy was inoperable during the Gulf of Alaska volume scatter measurements. Therefore, SUS had to be deployed directly from the tending surface ship. As will be shown, this modified operations procedure has important implications with regard to the noise floor for the measurements.

The Scattering Equation and Basic Assumptions

$$S_V(f,z) = 10\mathrm{Log}\left[\frac{I_R\left(c\,(t_0 + t_s) - L + 2d\right)^2}{4\pi cE\left[f_0(1 - \cos\theta_0)/f\right]}\right]$$

where: $S_V(f,z)$ = scattering strength as a function of frequency and depth in dB//m^{-3}
I_R = noise corrected beam reverberation intensity
c = average sound speed
t_0 = arbitrary start time of endfire beam reverberation time series
t_s = time difference between t_0 and onset of shock wave
L = array length
d = distance between array mid-point and detonation depth
E = energy flux density of explosive source
f_0 = design frequency of the acoustic aperture
θ_0 = 3 dB half beamwidth at frequency f_0
f = incremental frequency

Assumptions:
- Distribution of scatterers is random and homogeneous over the equi-time ellipse.
- Density of scatterers within an elemental volume *dV* is large.
- Absence of multiple scattering.

VuGraph 4

The scattering equation shown in VuGraph #4 is used to calculate volume scattering strength as a function of depth and frequency, $S_V(f,z)$. It was first developed by Stockhausen and Figoli (1973) for the bistatic source/receiver geometry and is directly derivable from the volume scatter sonar equation. The numerator on the right side of the equation consists of a measured reverberation level and a transmission loss term. The denominator consists of a source level term, E, and a frequency dependent volume correction term. Other constants in the equation make the equality dimensionally correct (units are dB//m^{-3}).

The phenomenological assumptions used in deriving this equation treat volume scattering as a stationary process within a given elemental volume. Multiple scattering effects are assumed to be negligible.

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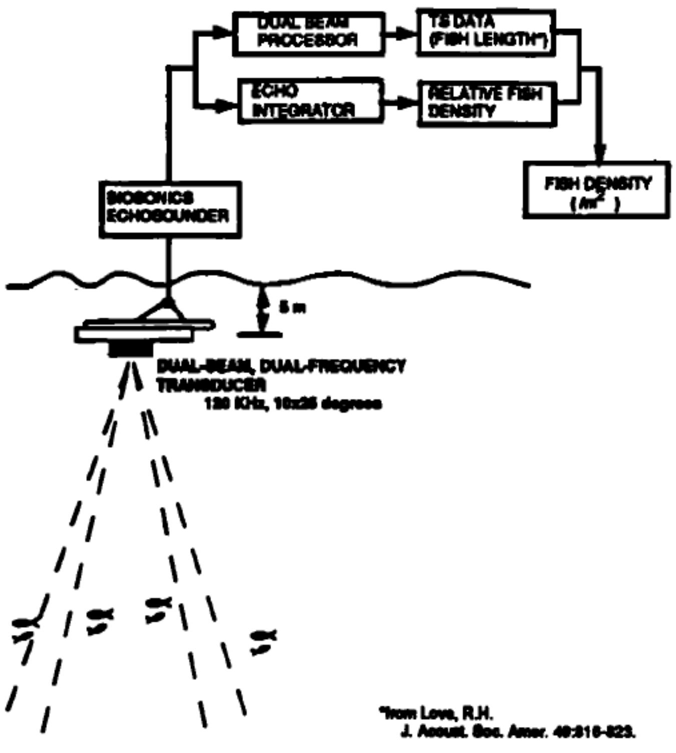
BioSonics Dual-Beam Hydroacoustic System



*from Love, R.H.
J. Acoust. Soc. Amer. 49:816-823.

VuGraph 5

VuGraph #5 shows the bioassessment measurement technique. As previously mentioned, the dual beam BioSonics Hydroacoustic Measurement (BSH) System was used to acquire the raw acoustic data. A high frequency (38 or 120 kHz), dual beam (10 and 25 degrees) transducer is energized such that short acoustic pulses are transmitted via only the narrow beam. Echoes are received on both the narrow and wide beams. The received acoustic signals are processed to yield (1) the target strength and depth distributions of discrete scatterers and (2) the density of scatterers within the insonified volume. Target strength is converted to fish length using Love's regression equation [Love, R.H. 1971]. These derived parameters aptly lend themselves as inputs into the NUWC Interval Column Strength Model (ICSM).

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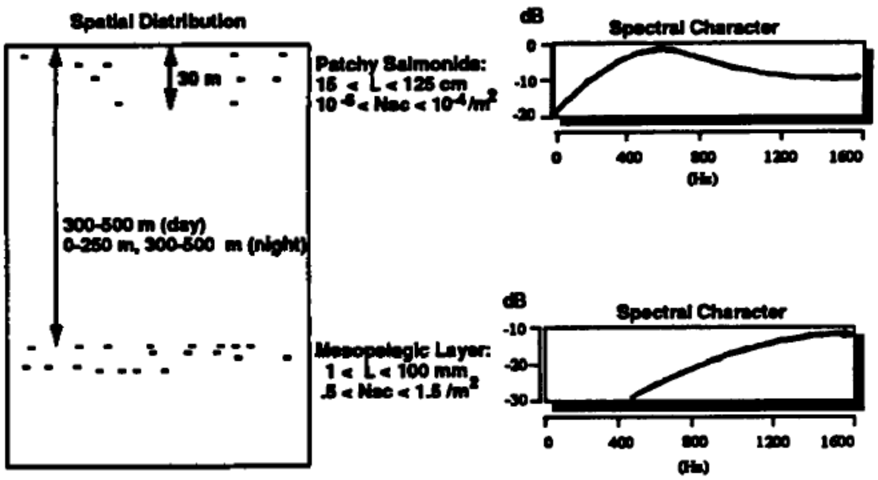
Expected Biologic Scattering in the Gulf of Alaska

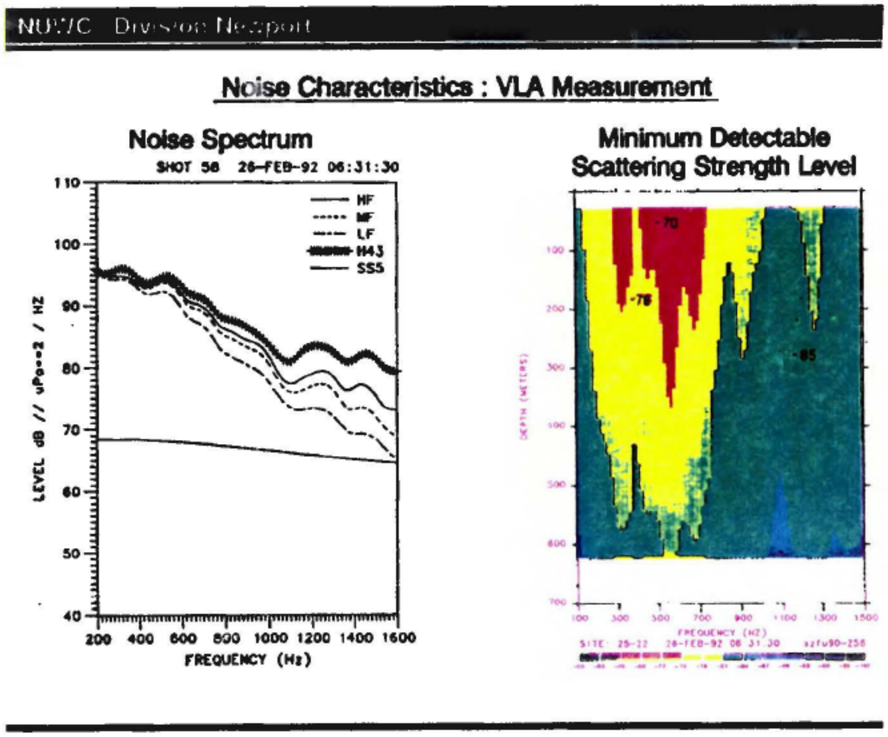


Sources: Saenger and Monti. NUSC Technical Report No. 9023, unpublished.
Frost and McCrone. US NMFS Bulletin 78 (4): 751-770, 1979.

VuGraph 6

The near surface distribution of fish in the region of the Gulf of Alaska where the volume scatter measurements were made is expected to be characterized primarily by salmonids (Sockeye, Pink, Chum, Coho and Chinook) extending from the surface down to approximately 30 m and occasionally as deep as 100 m. The highest concentration of these fish occurs in the upper 10 m. These salmonids congregate in loose, patchy schools with densities on the order of 10^{-4} to 10^{-6} fish per square meter. They possess swimbladders which typically resonate between 200 and 1600 Hz when excited by acoustic energy.

A mesopelagic layer is also expected in this region, consisting primarily of myctophids. This layer is expected to be present at depths between 300 and 500 m for both day and night. During nighttime, the layer tends to bifurcate, with some fraction of the resident population moving closer to the surface. Within the layer densities are high; i.e., on the order of 1 fish per square meter. These fish possess swimbladders and typically resonate at frequencies above 2000 Hz when excited by acoustic energy. However, at night, when the layer separates, those fish moving toward the surface can become important contributors to low frequency volume scattering.

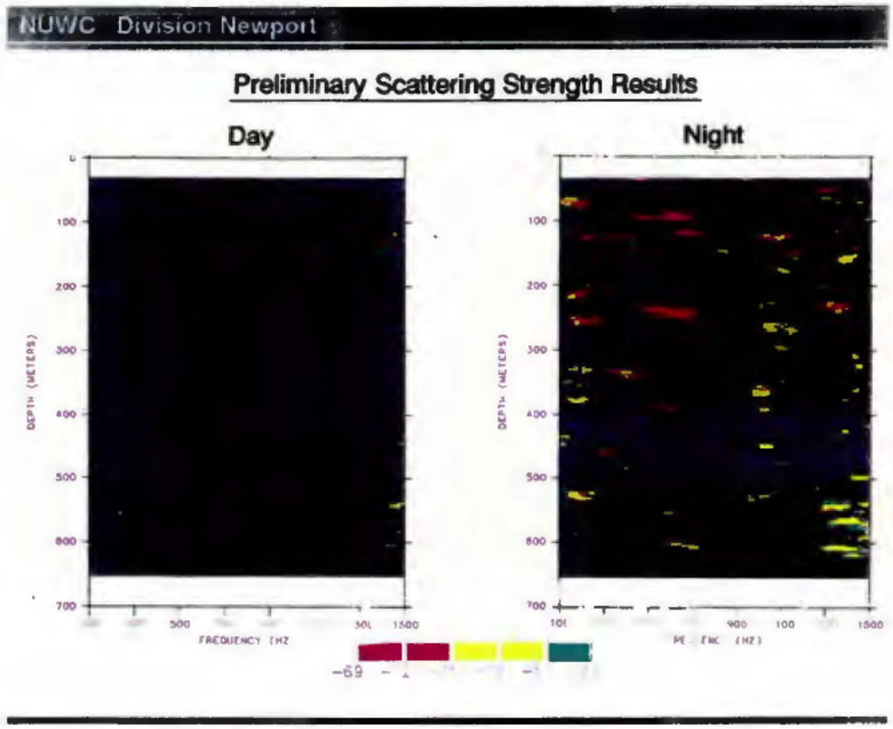


VuGraph 7

As stated previously, the ORCA buoy, which is used to deploy SUS charges for the VLA volume scatter measurements, was inoperable during the Gulf of Alaska tests. Therefore, the surface tending ship (M/V Amy Chouest) was required to remain in close horizontal proximity to the VLA to facilitate the shipboard deployment of the SUS. As a consequence, the ship was located within the surface patch insonified by the upward endfire beams of the VLA. Thus, the Amy Chouest ship generated noise dominated the 'ambient noise' field seen via the VLA LF, MF and HF subarrays.

Typical noise spectra as measured with each of the three subarrays, as well as an omnidirectional hydrophone (H43) within the array, are shown in the left panel of VuGraph #7. These measured levels are compared to a sea state '5' noise spectrum derived from the NUWC ambient noise model. This result illustrates that the measurement was platform noise limited, and that the platform noise exceeded the expected ambient noise levels by 10 to 20 dB.

The measured noise spectra have been mapped into scattering strength space to yield the minimum detectable scattering strength levels which could be derived in this noise environment. These levels are shown in the right panel of VuGraph #7. This result essentially shows the 'detection threshold' for measuring volume scatter within each depth/frequency bin. As illustrated, detection thresholds are highest in the near surface region, particularly in the 400 to 600 Hz spectral region.



VuGraph 8

Shown in the two panels of VuGraph #8 are the day/night averages of scattering strength, as measured with the SUS/VLA system. As illustrated in the previous vugraph, these measurements were platform noise limited. Due to the high noise level, little to no biological scattering is evident in these results.

The number of data sets for the daytime results are slightly better than those for the nighttime results; i.e., 14 samples versus 6 samples. As a result, it is believed that the scattering levels in the nighttime panel are due to noise events exceeding threshold. These events are not well correlated in space, as would be expected for biologic scattering. At the deep depths there is evidence of a possible mesopelagic layer in the nighttime measurements where there is activity at about 600 m over the 1300-1600 Hz spectral region. This is believed to be scattering and not noise because the signal-to-noise ratio for these depth/frequency bins is relatively good.

The high platform noise levels of the M/V Amy Chouest and the close horizontal proximity of the ship to the VLA, make VLA measurements of volume scatter, using received levels having a reasonable dynamic range above the noise, impossible. This problem, coupled with a nonfunctional ORCA buoy, resulted in a difficult situation for measuring volume scatter.

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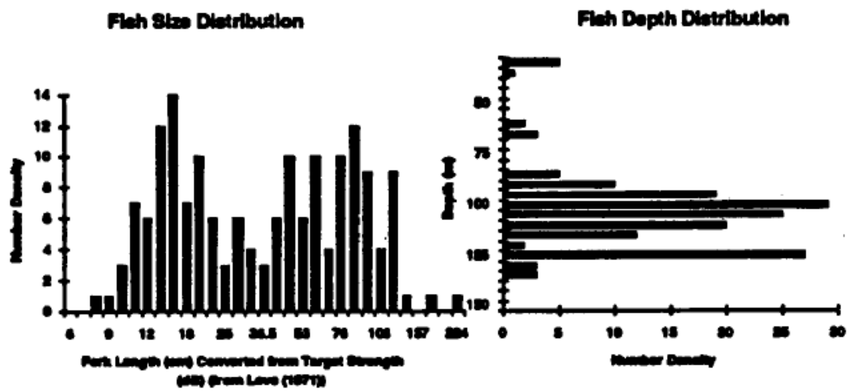
Bioacoustic Assessment Results
(upper 150 m)



Standing Crop Estimate: **Upper 150 m: 5.9×10^{-5}/m^2**
Mesopelagic Layer Not Insonified

VuGraph 9

Fish size and depth distributions derived from the bioacoustic survey system during the Gulf of Alaska measurements are shown in VuGraph #9. These results were derived from a 12-hour daytime deployment of the survey system. Since the system was operated at 120 kHz, measurements limited in water depth coverage allowing the insonification of only the 10 to 150 m depth interval.

The measured size distribution of the fish which was derived from target strength data is shown in the left panel. The distribution is bimodal with mean fork lengths of approximately 17 cm and 75 cm. These sizes are consistent with that expected of salmon in this ocean region; excepting those outliers beyond 125 cm. These may be a result of algorithmic limitations in converting target strength to fish size. The standing crop estimate of $5.9\text{x}10^{-5}/\text{m}^2$ is also consistent with expected densities of salmon in the Gulf of Alaska.

Shown in the right panel is the depth distribution of these targets (fish) in the upper 150 m. Roughly 90% of the daytime targets are located at or near 100 m depth. This depth correlates well with the thermo/halocline. Although it is well known that biologics tend to congregate at water mass boundaries, it is not expected that salmon would migrate to this depth. It is of interest to note that a concentration of targets located at or near a depth of 100 m was also revealed in measurements taken in this same ocean region two years prior to these Gulf of Alaska tests. At present, the 100 m biologics layer is neither expected nor explainable.

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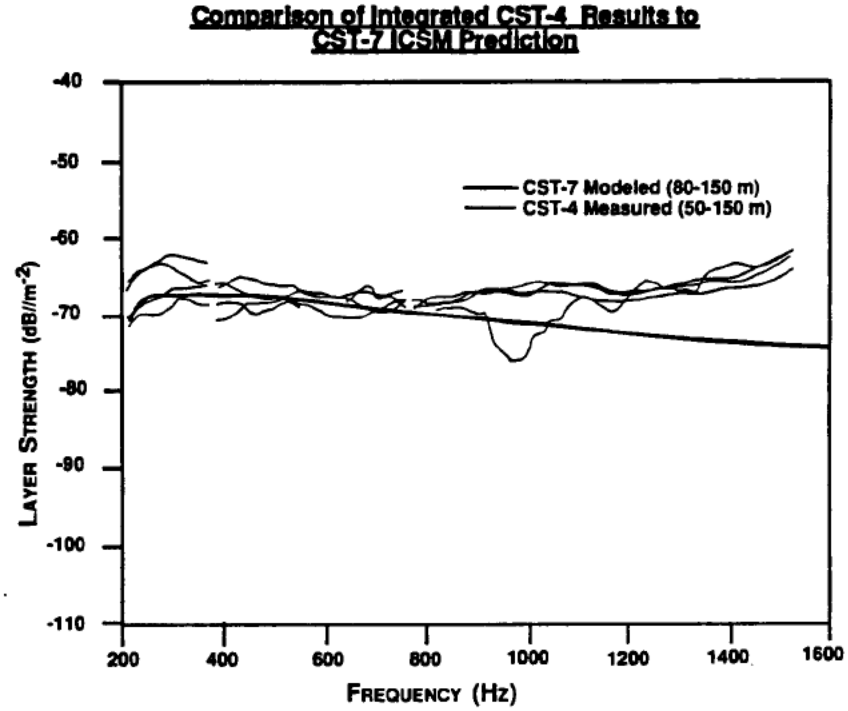

VuGraph 10

The derived biological distributions and standing crop estimates were used as input parameters to the NUWC Interval Column Strength Model (ICSM) to predict layer strength for the 80 to 150 m water depth interval. The resultant prediction is shown in VuGraph #10. Also plotted are results from the volume scatter measurements made in the Gulf of Alaska during the CST-4 exercise, two years prior to these CST-7 measurements, as reported in Saenger and Monti (1991).

These spectra are relatively flat as a function of frequency, but portray a slight low frequency swimbladdered fish resonance effect at ≈300 Hz. The agreement between CST-4 measured and CST-7 modeled results is considered excellent, indicating that, in a statistical sense, the species, sizes and number density of fish which occupied the 100 m scattering layer during the present CST-7 study were similar to those that existed during the CST-4 measurements. The divergence seen between the measured and predicted results at frequencies above 1000 Hz is believed to be a result of the voltage threshold setting used with the BSH sonar system which was adjusted to disregard echoes from fish shorter than 9 cm in length.

Summary

- Due to ship noise limitations, scattering strength could not be measured below -70 dB//m^{-3} in near surface and -85 dB//m^{-3} in mesopelagic strata.
- Measured biologics size distributions agree with that expected from historical data excepting outliers beyond 125 cm in length.
- An unexpected and currently unexplained layer was identified at ≈100 m depth. Correlates well with thermocline depth. Requires further investigation.
- Analysis on-going to determine feasibility of using HF bioacoustic assessment sonar to predict LF column and layer strengths.

VuGraph 11

In summary, the primary objective to demonstrate the use of high frequency bioacoustic data for the purpose of estimating low frequency volume (biological) scattering characteristics was not fully attained due to experimental difficulties. The ambient noise floor during these February 1992 Gulf of Alaska direct path, low frequency volume scatter measurements was excessive. Volume (biologics) scattering levels did not exceeded the noise floor and it was therefore impossible to extract layer and column scattering strength spectra. Efforts are presently underway to improve the signal-to-noise ratio using correlation processing with the hopes of yielding the measured layer and column strength spectra.

The associated bioacoustic measurements made during these tests show good agreement with published data in size distribution and density. However, the measured depth distributions do not agree with historical data. The biologics layer (presumably salmonids) located at the thermocline depth was not expected and needs further investigation.

Work is ongoing to optimize the use of high frequency (≈38 kHz) bioassessment sonar measurements in conjunction with direct path, low frequency (≈200-1500 Hz) volume scatter measurements.

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